



Assimilation: Asymmetry between Brightness and Darkness?

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A pincushion formed by four arcs on a gray background looks darker when the arcs are black, and lighter when the arcs are white. Yet, a matching experiment shows that this difference is relative. Whereas the apparently darker pincushion requires a matching luminance that is lower than the background luminance (i.e. assimilation), the apparently lighter pincushion curiously is also matched to a darker-than-background value (i.e. simultaneous contrast). A change-over in direction of a higher luminance occurs only at the lowest contrast. The size of the decrement required for matching the brightness of the pincushions increases with increasing contrast of the inducing stimulus, as well as with viewing distance. Assimilation is found also in the domain of color, however, only when the luminance of the colored inducers is below that of the background. Analogous asymmetries in the perception of darkness and lightness are discussed.

Assimilation Brightness spreading Simultaneous contrast

INTRODUCTION

Assimilative changes of brightness and/or color rendering the appearance of an area more similar to its surround (i.e. similitude), have been known since the pioneering studies by Chevreul (1839) and von Bezold (1874) in the last century. These authors described assimilation for narrow regions of a stimulus pattern, such as the weaving pattern of a gobelin or the black and white arabesques on a chromatic ground ["spreading effect" (Evans, 1948; Munker, 1970)]. In such patterns, light lines lighten and dark lines darken adjacent areas, contrary to simultaneous contrast (Mach, 1865; Hering, 1878).

In this century, Prandtl (1926, 1927) and Helson *et al.* (Helson, 1963, 1964; Helson & Joy, 1962; Helson & Rohles, 1959) studied the brightness spreading effect using black and white lines on various backgrounds. It was found, as with arabesques, that when white and black striations were superimposed onto the same gray background, the intervening gray areas were judged lighter for the white stripes and darker for the black stripes. However, the perceived lightness in each case depended on the width, spacing, and reflectance of the stripes (Helson & Rohles, 1959; Helson & Joy, 1962; Helson, 1963). Thin lines of 3–4 min arc with equally

thin interspaces were optimal for eliciting assimilation, although separations of up to 1 deg still produced some effect. Helson (1964) hypothesized that fine lines result in summation producing assimilation, whereas coarse lines result in inhibition, producing contrast. He proposes that the two phenomena lie on a single continuum with a zone of neutrality wherein there is neither effect (for reviews see Steger, 1968, 1969).

We show that assimilation can also occur for a gray area enclosed by disk-shaped stimuli of alternating black and white rings. Figure 1 demonstrates assimilative brightness changes within the pincushion-like spaces surrounded by quarter arcs of different polarity. Clearly, the pincushions bounded by black arcs appear to be darker than the pincushions bounded by white arcs although both areas have the same luminance. These perceived changes are opposite to what one would predict from simultaneous contrast.

Several questions arise from these observations: do the brightness changes depend on the contrast of the inducing arcs relative to the background? How are they affected by viewing distance and arc width? Is there an effect of color? In this study, we have tested the role of these parameters on assimilation using a matching technique.

EXPERIMENT 1: FIGURE-GROUND CONTRAST

Here we measured the perceived strength of the induced brightness changes in the test pattern as a function of the contrast between the dark and bright rings relative to the background.

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Method

The pattern shown in the upper row of Fig. 1 was used throughout the experiment. Stimuli were generated by a PDP 11/23 computer and displayed on a color monitor (BARCO CTVM 2/52 H with 10-bit wide R, G, and B inputs). We set the luminance increment of the brighter rings equal to the luminance decrement of the darker rings to keep the average luminance of the stimulus pattern constant. The chromaticity was neutral ($x = 0.33$, $y = 0.33$). Eight contrasts ranging from 0.05 to 0.86 on a background of 18 cd/m² were presented. The Michelson contrast values and the corresponding luminance values of the dark and bright arcs as well as of the background are given in Table 1. The pincushions were 6 cm across (1.7 deg) with each arc subtending 0.5 cm (0.14 deg). Observers viewed the stimuli binocularly from a distance of 2 m.

The observer's task was to adjust the luminance of a 1.7 deg round matching field displayed on the uniform background to the right of the test figure, until its brightness matched that of the enclosed bright or dark pincushions. The starting luminance in each case was identical to that of the background (i.e. zero contrast). Subjects looked into the middle between the pincushion to be matched and the nearby matching field which was always in the same position. No fixation point was used as the match did not seem to be affected by the exact location of the target nor by eye movements. To enhance the resolution of the matching function, we changed only half of the pixels within the matching field. This procedure allowed a better and more precise (by a factor 2) control of the brightness match. The subjects did not perceive the individual dots in the matching field at all.

Stimulus contrast was randomized and five measurements were consecutively taken at each contrast setting for both the light and the dark pincushions. Both authors, CDW, LS, and a third observer, JT, served as subjects. To better perceive the induced brightness changes and to facilitate the match, subjects assumed a global view of the stimulus pattern.

Results

Figure 2 shows matching luminance plotted as a function of figure-ground contrast for three observers. With increasing contrast of the stimulus to the background, matching luminance for the pincushion bounded by the dark arcs (●) first decreases, and then levels off. Contrary to expectation, matching luminance for the pincushion bounded by the bright arcs (○) also decreases. Only at the very lowest contrast setting is the matching luminance higher than, or equal to, that of the background. The difference in matching luminance for the light and dark pincushions becomes smaller with increasing contrast and, for subjects CDW and JT, approaches zero.

The unexpected darkening of the "light" pincushions was also observed when the stimulus pattern was shown transiently with the eight contrast values presented as a triangular ramp lasting from 100 to 1000 msec. There was

a pronounced darkening of the "light" pincushions in direction of, but not exceeding, the brightness of the background. In comparison, the brightness of the dark pincushions changed little.

EXPERIMENT 2: VIEWING DISTANCE AND ARC WIDTH

In this experiment we varied the viewing distance to investigate the effect of visual angle subtended by the inducing pattern on the strength of assimilation. Arc width served as a parameter.

Method

The stimulus pattern was presented at viewing distances ranging from 1 to 10 m with narrow (0.25 cm), medium sized (0.5 cm), and wide inducing arcs (1 cm). The disks had the same diameter (6 cm) and the pincushions were 6 cm across in all cases. (For conversion to visual angle: 1 cm at 1 m corresponds to 0.57 deg.) Background luminance was again 18 cd/m² and Michelson contrast between the bright and dark arcs was 0.33. Two subjects matched the brightness of the dark pincushion using the same procedure as before. Four measurements were taken at each distance.

Results

Figure 3 shows matching luminance plotted as a function of viewing distance for two observers. Results for the medium arcs (○) yield the strongest assimilation at all distances. Matching luminance starts well below the background luminance and decreases with increasing viewing distance. Matching luminance for the wide arcs (△) decreases at approximately the same slope, but at a higher level. In comparison, matching luminance for the narrow arcs (□) remains relatively constant. The curves for the narrow and wide arcs cross over at distances between 4 and 7 m. Note that in no case did we find a transition from assimilation to contrast for any of the patterns at any of the distances tested.

EXPERIMENT 3: COLOR

So far, all experimental patterns were achromatic consisting of various shades of gray. In this experiment we asked whether comparable effects could also be obtained in the chromatic domain when colored rings are shown on a colored background?

Method

Colored inducing arcs were used on a colored background. The arcs were red (color coordinates $x = 0.462$, $y = 0.323$) and green ($x = 0.384$, $y = 0.528$), and they were presented on five different background colors: green ($x = 0.383$, $y = 0.532$), yellow-green ($x = 0.404$, $y = 0.482$), yellow ($x = 0.436$, $y = 0.399$), yellow-red ($x = 0.446$, $y = 0.373$), and purplish ($x = 0.472$, $y = 0.303$). The luminance of the colored arcs was 20.3 cd/m², while the luminance of the colored

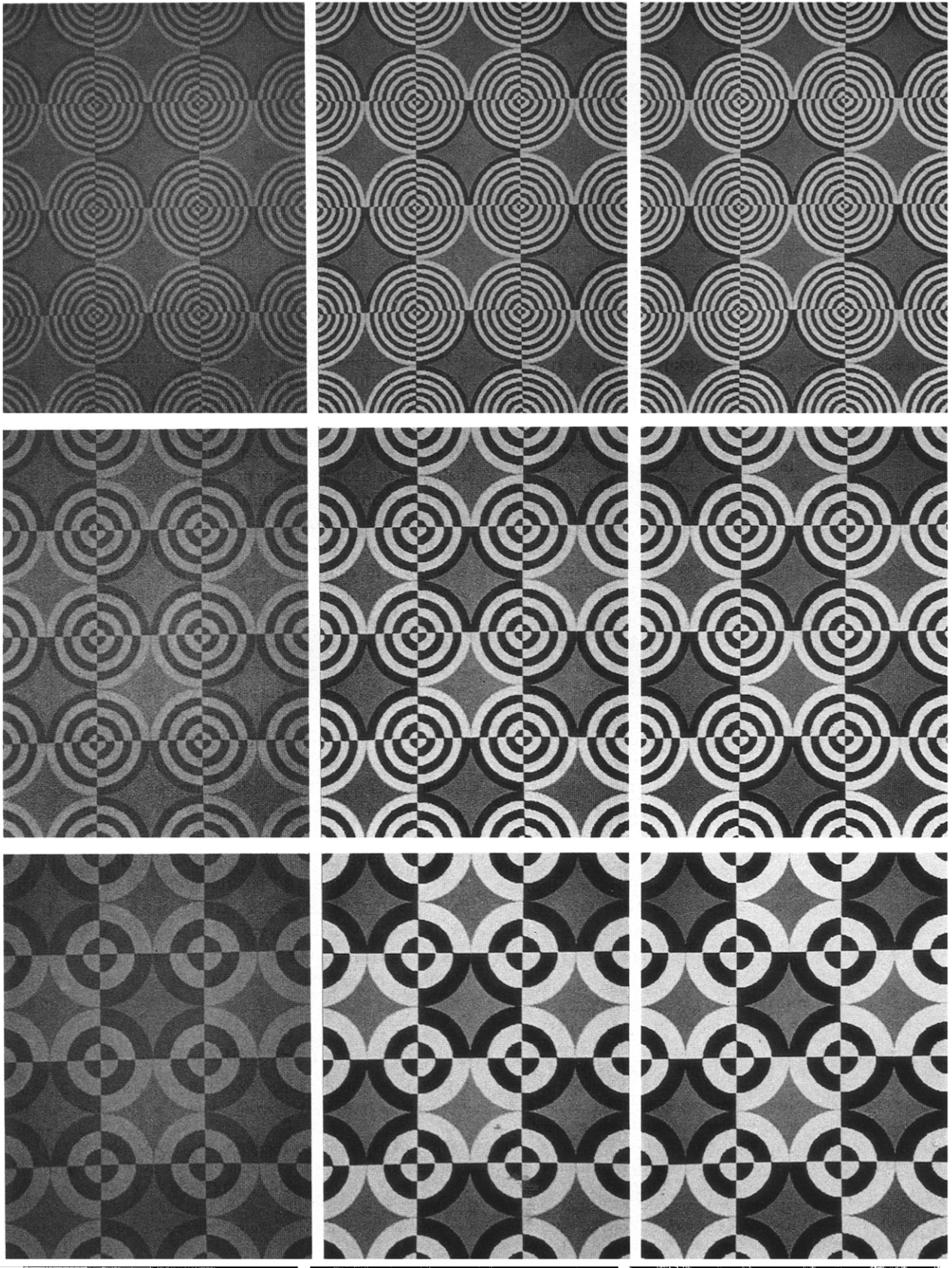


FIGURE 1. The pincushions bounded by the black arcs appear to be darker than the pincushions bounded by the white arcs, although both have the same luminance. These assimilative changes are obtained regardless of the number, width, and contrast of the inducing rings. However, when matched the "lighter" pincushion requires a luminance lower than that of the background, suggesting contrast. [Modified from de Weert and van Kruysbergen (1987) and de Weert (1991).]

TABLE 1. Contrast and luminance values used

Michelson contrast*	Luminance values of arcs		
	Dark arcs (L^-)	Background	Light arcs (L^+)
0.05	17.10	18.0	18.90
0.10	16.20	18.0	19.80
0.14	15.48	18.0	20.52
0.17	14.94	18.0	21.06
0.33	12.06	18.0	23.94
0.50	9.00	18.0	27.00
0.66	6.12	18.0	29.88
0.86	2.27	18.0	33.33

*Michelson contrast: $\frac{(L^+ - L^-)}{(L^+ + L^-)}$.

backgrounds was either higher (25 cd/m^2) or lower (17 cd/m^2). In two instances, the luminances of the arcs were adjusted (21.8 and 18.5 cd/m^2 , respectively) so as to straddle the background luminance (20.4 cd/m^2). We also used isoluminance between figure and ground.

Results

When the background luminance was higher than the luminances of the arcs, assimilative color changes occurred with both red and green arcs. For example, a yellow pincushion bordered by red arcs assumed a reddish tint, whereas a yellow pincushion bordered by green arcs assumed a greenish tint. The threshold luminance of the background required to elicit these hue changes was about 21 cd/m^2 , just slightly above the luminance of the arcs. However, when the luminance of the colored background was below the luminances of the red and green arcs, there was no hue change. Furthermore, when the luminance of the yellow background was in between the luminances of the red and green arcs (a colored analog of the achromatic case in Fig. 1), we again perceived color assimilation only on pincushions bounded by arcs of lower luminance.

Neither assimilation nor contrast was found at equiluminance. Also, when the green arcs bounding the pincushion were equiluminant, while the luminance of the red arcs was varied over a large range, there was no change in color or brightness, suggesting that the green arcs acted as a perfect barrier.

DISCUSSION

From the study of simultaneous contrast it is known that there is symmetry in the perception of positive and negative luminance contrasts (Burkhardt, Gottesman, Kersten & Legge, 1984). In the pattern used in this study, the bright and dark pincushions also seem to be symmetric: both are equally conspicuous and there is no doubt about their polarity. As Expt 1 has shown however, when the brightnesses of the two kinds of pincushions are matched to an outside comparison stimulus, the apparently brighter pincushion is actually matched by a luminance that is lower than the luminance of the background and close to the matching luminance for the dark pincushion. A change-over in direction of a higher luminance occurs only at the lowest contrast. We

therefore conclude that the mechanisms underlying these two phenomena are different. While the matches for the dark pincushion are consistent with assimilation, the matches for the light pincushion indicate contrast. Note however, that in nearly all cases the pincushions

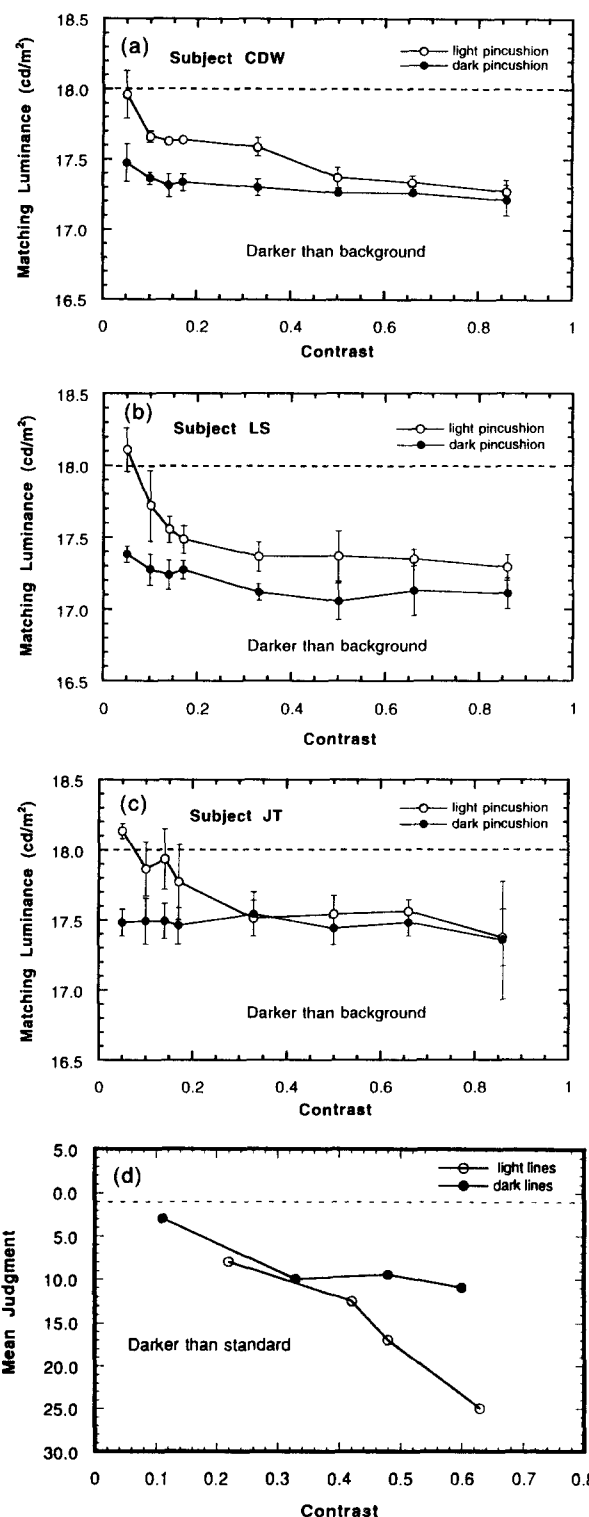


FIGURE 2. Matching luminance plotted as a function of the contrast of the inducing arcs for a light pincushion (\circ) and a dark pincushion (\bullet). Background luminance was 18 cd/m^2 (dashed horizontal line). (a) Subject CDW, (b) subject LS, (c) subject JT. Data points are averages of five measurements. Error bars = ± 1 SD. (d) Results from Beck (1966, Fig. 1) are replotted for comparison.

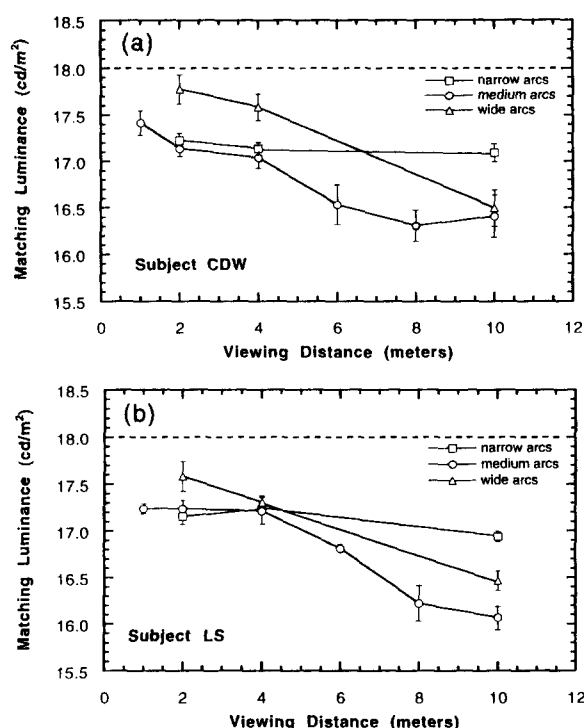


FIGURE 3. Matching luminance for the dark pincushion plotted as a function of viewing distance (in m) for three widths of the inducing arcs. Contrast was 0.33, background luminance was 18 cd/m². (a) Subject CDW, (b) subject LS. Data points are averages of four measurements. Error bars are ± 1 SD.

surrounded by white arcs are still lighter than the pincushions surrounded by the dark arcs. This is also indicated by the matching luminances which are higher.

Our results confirm earlier findings by Beck (1966) who placed stripes of various reflectances and widths on a standard gray background. Using a rating scale for brightness judgments, he found that the striated fields were always judged darker than a uniform control patch, regardless of the polarity of the stripes. As in our experiment, contrast occurred when the reflectance of the lines was above the reflectance of the background and assimilation when the reflectance was below that of the background. Paradoxically, at high contrast, the darkness induced by the bright stripes was even stronger than that for the dark stripes. Figure 2(d) shows Beck's data replotted on a contrast scale.

Festinger, Coren and Rivers (1970) likewise found that a gray patch with white stripes, when matched by adjusting the brightness of a spinning rotor, yielded a significantly lower (darker) value than the same patch with black inducing stripes, although the former looked lighter than the latter.

An asymmetry for increment and decrement stimuli has recently been reported by Hamada (1984) in half-wave-rectified grating stimuli (half-gratings representing the positive or negative polarity only). In such patterns the bars with the higher luminance were matched to darker, not brighter, Munsell values than the background. The same applied to the Craik-O'Brien and Ehrenstein illusions, where the bright illusory areas in both cases were matched to a gray darker than the background (Hamada,

1985, 1987). Hamada (1991) attributed these effects to a global "nonantagonistic" form of inhibition. This is consistent with findings by Kurtenbach and Spillmann (1992) who obtained Westheimer curves with the sensitization branch missing (i.e. lack of lateral inhibition) when a bright center with a dark surround was used for a stimulus. For the converse stimulus (dark center, bright surround) sensitization was pronounced. A similar asymmetry was reported by Moulden and Kingdom (1989) in White's effect (see also Kingdom & Moulden, 1991).

Assimilation and receptive fields

To account for assimilation, the early researchers suggested stray light and irradiation (for a review see Tschermak, 1903). More recently, neuronal spatial integration within receptive field centers (DeValois & DeValois, 1975; Hurvich & Jameson, 1966, 1974; Jameson & Hurvich, 1975), weighted averages across distance (Reid & Shapley, 1988), or large receptive fields without center-surround antagonism (de Weert, 1991) have been proposed as an explanation. The assumption of synergistic processing might explain why a transition from assimilation to contrast is difficult to find (Fach & Sharpe, 1986; Moulden, Kingdom & Wink, 1993). In this context it should be noted that in Expt 2 inducing patterns with narrow arcs elicited less assimilation (contrary to Helson's conclusion) than medium and wide arcs (see also de Weert, 1991, Fig. 2). This finding might suggest that there is an optimal ratio between arc width and pincushion (large pool size, Fig. 3).

The results obtained with colored stimuli in Expt 3 are consistent with those of Expt 1 showing that stimulus decrements are required to produce assimilation. The prediction by DeValois and DeValois (1988) that there should be stronger assimilation for color than for lightness, because of the lack of lateral inhibition in chromatic receptive fields, is not borne out by our results. Compared with the brightness effects, the color changes were quite subtle (see however, Kanizsa, 1979). The finding that the inner, green arc acted as barrier against the farther, red arc shows that second-order effects due to interaction between rings alternating in color are likely to be small.

Assimilation and figure-ground perception

From a structural point of view, Festinger *et al.* (1970) came to the conclusion that brightness assimilation is likely to be found only when the region of the stimulus pattern whose brightness is to be matched is perceived as background. With regard to our stimulus pattern, this would imply that the pincushions bounded by the dark arcs were seen primarily as "ground", hence assimilation, whereas the pincushions bounded by the bright arcs were perceived predominantly as "figure", hence contrast. A similar idea emerges from the observation by Kanizsa (1979, Figs 8.2 and 8.3) that small gray fragments with fuzzy borders dispersed on a uniform gray background favor assimilation, whereas a well-defined target of the same

gray surrounded by the same background favors contrast. The advantage of our specific display of the assimilation/contrast effect is that both the incremental case and the decremental case are presented simultaneously in the same picture. If a change of viewing strategy occurred, it would have affected both the darkness spreading and the brightness spreading. Yet, we never noticed any change in behavior for the darkness system and, consequently, we may assume that fluctuations in the way of viewing were presumably not very influential.

It is interesting to note that in order to see the brightness changes in Fig. 1, subjects preferred a global view of the stimulus pattern. There are similar reports in the literature. Burnham (1953) and Beck (1966) showed that casual observation without rigid fixation facilitates assimilation. Festinger *et al.* (1970) emphasized the need for global viewing. Kanizsa (1979) distinguished between the two modes of observation calling one "natural, spontaneous, global" and the other "analytic, artificial". And a number of illusory effects such as the Hermann grid illusion, the Ehrenstein illusion, and the Kanizsa triangle are likewise dependent on free viewing and a broad distribution of attention (Spillmann, 1994; Spillmann & Dresch, 1995).

What is the anatomical site of these effects? One might speculate that the brightness changes in this study originate at a relatively early level in the visual pathway. Reid and Shapley (1988) suggest a locus "primarily outside" Area 17. A prestriate location would be consistent with Schiller's (1992) neuropharmacological distinction of two visual subsystems (see also Jung, 1973), one for the perception of brighter (ON) and another for the perception of darker (OFF). Both pathways remain functionally and structurally separate from the retina to the cortex. From our results, it would seem that they also contribute differently to the perception of assimilation.

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